AERODYNAMIC DATABASE CONSTRUCTION FOR FLIGHT DYNAMIC MODEL OF LOW SUBSONIC FIXED-WING VTOL UAV

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ABSTRACT

During Unmanned Air Vehicle development, some verification process such as flight simulation and flight test are necessary. These verification process is aimed to verify the compliance of UAV performance with its Design Requirement and Objectives. In order to do accurate flight simulation, the accurate aerodynamic coefficients prediction is required. Wind Tunnel test is the most accurate method among others but it is not always available. Thus, the computational aerodynamics method was implemented. Among well-known Computational Aerodynamics methods to predict the aerodynamic coefficients, Vortex Lattice Method and Computational Fluid Dynamics are frequently used during aircraft conceptual design process. VLM gives less accurate prediction after separation flow occurs, meanwhile CFD method provides options for modeling the turbulent flows but requires high cost and time. In this paper, construction of aerodynamic coefficients data of fixed-wing VTOL UAV was explained. In this case, the aerodynamic coefficients data must be constructed as accurate as possible with limited computational resources and without wind tunnel data. Three different levels of geometry complexity of fixed-wing UAV were used in Vortex Lattice Method and full configuration geometry was used in CFD simulation for longitudinal force and moment analysis. The result is VLM with simplified geometry was considered as the best match with CFD result for longitudinal motion. Thus, the construction of other aerodynamics coefficients for lateral and longitudinal motion was done by the simplified model. The decision of kinds of aerodynamic coefficients was based on open source flight dynamics module JSBSim.

INTRODUCTION

In order to verify the designed flight envelope and flight performance of the UAV, simulating the UAV using flight simulator or just flight dynamics model is needed. The flight simulator software consist of flight dynamic model, control system model and visualization. The flight dynamics model is the most important component in flight simulator because it calculate the flight data of the UAV such as attitude, altitude and other flight data for specific given input and flight condition. In order to give proper output for specific given input, flight dynamics model requires correct numerical modeling, aerodynamics and thrust coefficients. During conceptual and preliminary design, aerodynamics prediction methods based on potential flow such as Panel Method and Vortex Lattice Method are widely used due to its less time and resources requirements. These methods are quite accurate on linear aerodynamic region but give significant error when separation flow occurs meanwhile CFD provides options to model the separation and turbulent flow around UAV. Hence, the aerodynamic prediction using VLM was corrected based on CFD result. In this paper, the process to generate a set of aerodynamics data using VLM and CFD was explained.

METHODOLOGY

Vortex Lattice Method

Vortex Lattice Method was formulated with assumption of incompressible and inviscid flow on lifting surface. The lifting surface is simplified by mean thickness and modeled as horseshoe vortex. The calculation of aerodynamic forces coefficients is by calculating the vortex strength or circulation. There are four main theorem to implement VLM, Biot-Savart law, Kutta-Joukovsky, Hermann von Helmholtz, and Prandtl lifting-line theory. According to Biot-Savart law, every vortex line of certain circulation induces velocity field (equation 1). Kutta-Joukovsky state that every vortex of certain circulation moving with velocity experience force (equation 2).

$$V = \frac{\Gamma}{4\pi}\int \frac{dl \times r}{|r|^3} \tag{1}$$

$$L = \rho V_\infty \Gamma \tag{2}$$

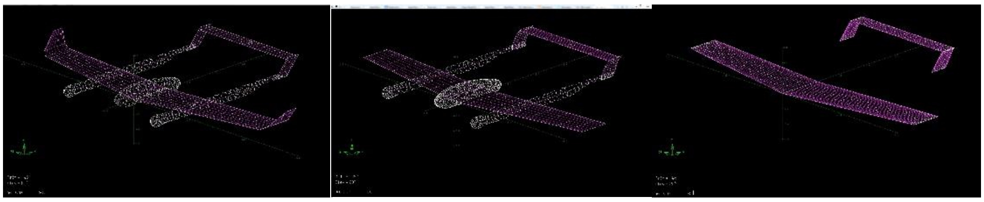

Figure 1. Geometry complexity comparison for VLM input

Implementation of VLM was done by using an open source code Athena Vortex Lattice (AVL). Vortex lattice independence study was done to compare the result for different density of lattice on lifting surface. Then, result comparison of different geometry complexity of AVL input was done. The most similar lift curve slope with CFD result of geometry input for AVL is the geometry without fuselage and winglet. Thus, this geometry input configuration was implemented for all cases.

Computational Fluid Dynamics

CFD provides accurate predictions for linear and non-linear aerodynamics due to its complex fluid formulation. Steady Averaged Navier-Stokes equation was used to model the flow around UAV. Navier-Stokes equation consists of continuity, momentum and energy equation. The direct calculation of original Navier-Stokes equation without any turbulence and energy assumption is too complicated, hence turbulence modelling is needed for this simulation. Equation 3 and 4 describe the main component of CFD which consist of continuity, momentum, and energy equation in normal and shear force. All the solutions of the equations are calculated iteratively.

$$\frac{\partial \vec{Q}}{\partial t} + \frac{\partial \vec{E}}{\partial x} + \frac{\partial \vec{F}}{\partial y} + \frac{\partial \vec{G}}{\partial z} = \frac{\partial \vec{E}_v}{\partial x} + \frac{\partial \vec{F}_v}{\partial y} + \frac{\partial \vec{G}_v}{\partial z} \tag{3}$$

$$Q=\begin{Bmatrix}\rho \\ \rho u \\ \rho v \\ \rho w \\ \rho e_t\end{Bmatrix}, E=\begin{Bmatrix}\rho u \\ \rho u^2+p \\ \rho uv \\ \rho uw \\ (\rho e_t+p)u\end{Bmatrix}, F=\begin{Bmatrix}\rho v \\ \rho uv \\ \rho v^2+p \\ \rho vw \\ (\rho e_t+p)v\end{Bmatrix}, G=\begin{Bmatrix}\rho w \\ \rho uw \\ \rho vw \\ \rho w^2+p \\ (\rho e_t+p)w\end{Bmatrix} \tag{4}$$

$$E_v=\begin{Bmatrix}0 \\ \tau_{xx} \\ \tau_{xy} \\ \tau_{xz} \\ \beta_x\end{Bmatrix}, E_v=\begin{Bmatrix}0 \\ \tau_{xy} \\ \tau_{yy} \\ \tau_{yz} \\ \beta_y\end{Bmatrix}, E_v=\begin{Bmatrix}0 \\ \tau_{xz} \\ \tau_{yz} \\ \tau_{zz} \\ \beta_z\end{Bmatrix}, \beta_x=u\tau_{xx}+v\tau_{xy}+w\tau_{xz}-q_x$$

In this work, the CFD calculation for aerodynamic coefficients prediction of fixed-wing VTOL UAV was initiated by grid independent study before simulating a set of longitudinal static force and moment coefficients. The number of final mesh element is approximated 16 million and ICEM CFD was used to generate the mesh. The simulation was done by using ANSYS FLUENT and k-epsilon turbulence model was used after comparison with SST k-omega. The convergence criteria is when the log-residual below 10e-4 or when the aerodynamic coefficient does not change significantly.

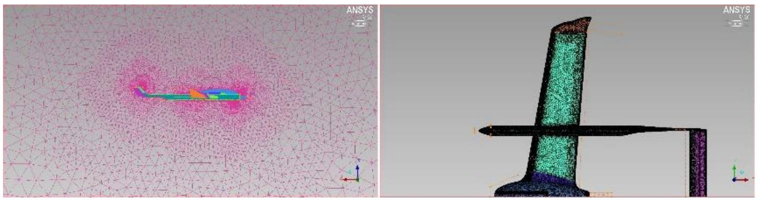

Figure 2. Mesh density distribution for CFD simulation of fixed-wing VTOL UAV

Flight Simulation Module, JSBSim.

JSBSim is an open source flight dynamics module which can be able to be implemented on open source flight simulation module such as Flight Gear. The next plan of the work is to implement the flight dynamics module for fixed-wing VTOL UAV so the construction of aerodynamics data set is based on the JSBSim format. The detail of the requested aerodynamics data set by JSBSim wil be explained in oral presentation.

RESULT

Different AVL result from different UAV configuration model was compared and the configuration without winglet and fuselage show the best match gradient with CFD for longitudinal aerodynamic data. Then, the required aerodynamic data by JSBSim was generated using Vortex Lattice Method. This set of aerodynamic data will be implemented on JSBSim flight simulation module.

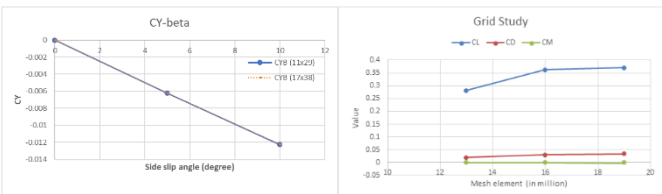

Figure 3. Lattice independence study for VLM (left) and grid independence study for CFD (right)

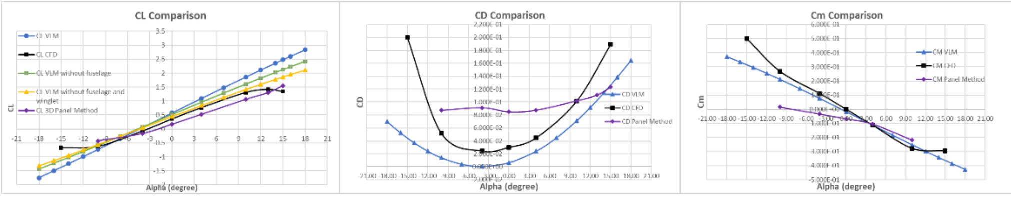

Figure 4. Aerodynamic coefficient comparison between Panel Method, VLM, and CFD

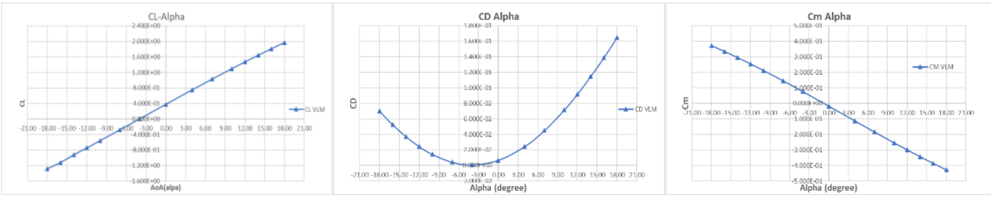

Figure 5. Longitudinal force and moment coefficients

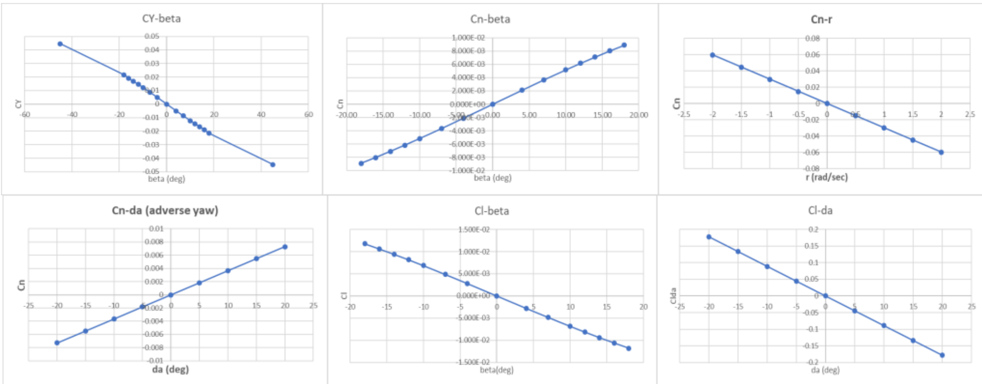

Figure 6. Lateral-directional force and moment coefficients

ACKNOWLEDGEMENT

This work was financially supported by the Ministry of Trade, Industry and Energy (MOTIE) and Korea Institute for Advancement of Technology (KIAT).

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